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Studies on Nicotine Fumigation In Greenhouses

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INTRODUCTION

Nicotine, as the greenhouse fumigant most often used (*3*)[2], is all the more important under the present wartime conditions because of the lack of certain imported insecticides, such as pyrethrum.

Several new methods have recently been introduced for the vaporization of nicotine as a fumigant. These include vaporization (1) by igniting nicotine-impregnated material inside a can, the vaporized nicotine being ejected under pressure (pressure-can method) (*4*, *7*), (2) by injecting nicotine into the exhaust pipe of a gasoline engine (exhaust method) (*1*, *14*), and (3) by passing atomized nicotine through a very hot pipe (*16*, *17*, *18*). In 1936 A. C. Johnson and L. A. Hawkins of the Division of Control Investigations developed an apparatus in which acetone solutions of nicotine were finely atomized into the air stream from a blower, which provided distribution. In the present work, studies have been made in the greenhouse on this

[1] The authors acknowledge the aid of C. C. Cassil, of the Division of Insecticide Investigations, who made some of the chemical analyses, and of R. C. Thompson, of the Bureau of Plant Industry, Soils, and Agricultural Engineering, who examined the lettuce crop after the fumigation.

[2] Italic numbers in parentheses refer to Literature Cited, p. 14.

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atomizer apparatus as well as on some of the other methods of vaporization. The effect of moisture, the length of the fumigation period, and other factors have also been investigated.

MATERIALS AND METHODS

The concentrated solution used in the work analyzed 94.0 percent of nicotine by weight. In the atomizer method this was diluted with acetone to 40 percent nicotine by volume. The atomizer apparatus (fig. 1) was placed at the center of the south end of the greenhouse with the

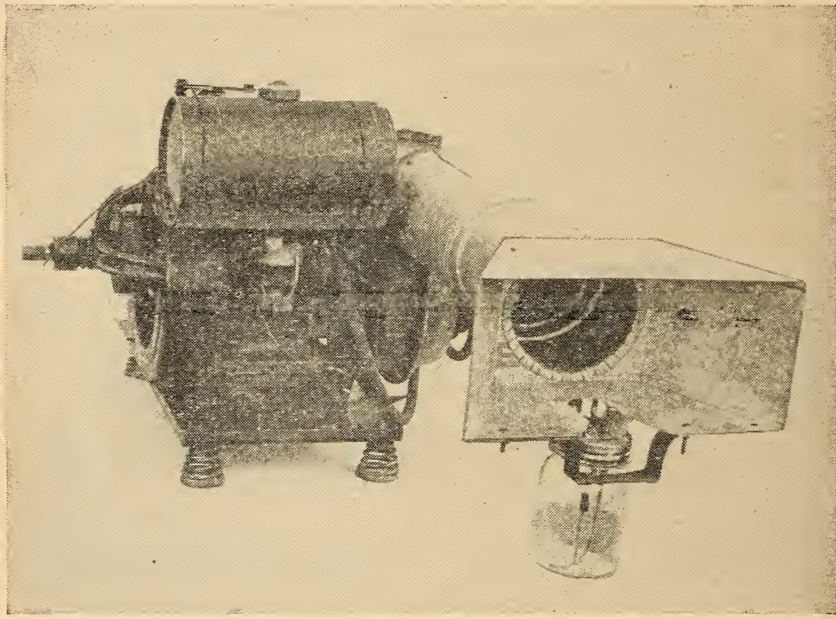

FIGURE 1.—Atomizer apparatus. Nicotine solutions were placed in the jar (right) from which they were atomized into the air stream of the blower. An air compressor placed in the rear provided air for atomization. The gasoline engine (left), provided power for the air blower and compressor.

blower pointing toward the opposite end. The rate of atomization was about 15 ml. per minute at 10 to 12 pounds air pressure. The blower sent out about 500 cubic feet of air per minute and was usually run for 15 minutes.

The pressure can (fig. 2), was a commercial product, the contents of which analyzed 13.73 percent of nicotine. A 1-pound can was placed in the center of the greenhouse, and smoke clouds were sent off toward both ends. It required about 4 minutes for complete discharge of the contents. Analysis of the residue remaining in the can after the discharge showed only a trace of nicotine.

The exhaust apparatus was set in the center of the greenhouse. The concentrated nicotine solution was introduced into the exhaust pipe at the rate of 3 ml. per minute from a dropping funnel, distribution being given simply by the exhaust gases. The temperature of the exhaust pipe was 300° C. soon after the beginning of operation and rose to 300° C. within 5 or 6 minutes.

The tobacco powder smudge (*15*) was a commercial product which analyzed 13.35 percent of nicotine. Small 2½-ounce piles were distributed down the center of the greenhouse. They required about 4 minutes for combustion. The nicotine paper (*8*) was a commercial product which analyzed 26.75 percent of nicotine. The papers were distributed down the center walk, one to each 2,000 cubic feet. Approximately 10 minutes were required for combustion.

Analyses of the nicotine concentrations obtained in the greenhouse were made by the micro methods of Spies (*19*) and Markwood (*6*). Adsorption tubes (*11, fig. 1-b*), were placed in various parts of the greenhouse at 10 to 12 inches from the ground. These were attached to aspirators outside the greenhouse, and 4- to 12-liter air samples were drawn through at about 500 ml. per minute.

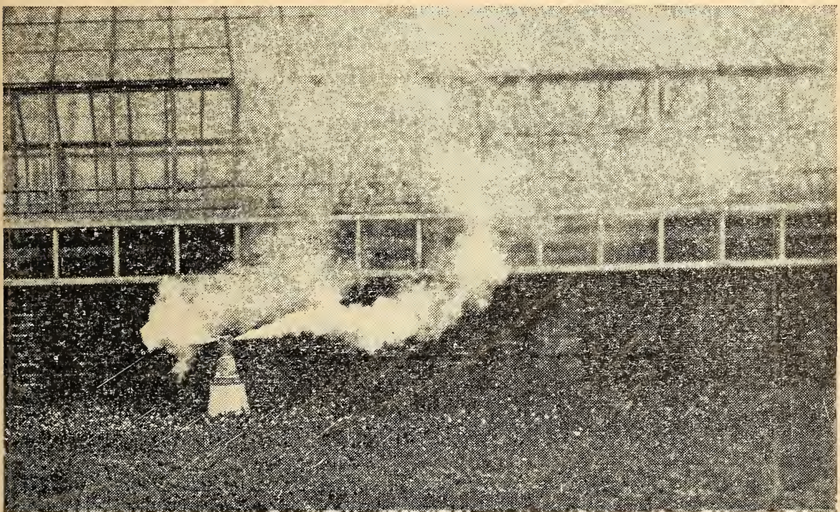

FIGURE 2.—Pressure-can method. Photo taken just after the start of ignition before pressure has reached a maximum. The left-hand smoke cloud has been broken up by a breeze. To raise it off the ground the can has been set on a flowerpot and that on an overturned bucket.

The fumigations were made in three 21,500-cubic-foot greenhouses (Nos. 1, 2, and 4), 75½ feet long and 28 feet wide. These were tightly built and were heated by hot-water pipes, temperatures being controlled by hand. The fumigations were begun late in the afternoon and continued overnight with ventilators tightly closed. Initial temperatures ranged from near 60° to 70° F., averaging 65°. Moisture conditions were varied by watering the plants and soil. Insecticidal tests were made on the green peach aphid (*Myzus persicae* (Sulz.)), usually on turnip, the potato aphid (*Macrosiphum solanifolii* (Ashm.)), on lettuce, and an aphid (*Myzus porosus* Sand.) on rose. Other insects were also tested. Usually 100 to 1,000 insects, averaging near 250, of a species on its host plant were exposed to a fumigation. Distribution was tested by placing the insects near the side at the north and south ends and center of the greenhouse.

At times fumigations were made at 1- or 2-day intervals in the same greenhouse. In unpublished work A. C. Johnson and A. M.

Phillips had noted a carry-over of nicotine sufficient to give considerable mortality of bean aphids (*Ahhis rumicis* L.) after a greenhouse had received several fumigations at short intervals with dosages of 0.15 ounce or more of nicotine per 1,000 cubic feet.[3] In the present work at lower dosages, tests were made in No. 2 greenhouse after it had been fumigated five times over a period of 26 days with 0.05- to 0.1-ounce dosages. A 90-liter aspiration made 7 hours after the last fumigation showed no nicotine. Insecticidal action against the melon aphid (*Aphis gossypii* (Glov.)) was also negligible.

STUDIES ON VARIOUS METHODS OF VAPORIZATION

The nicotine concentrations obtained in the greenhouse at various dosages with the atomizer method are shown in figure 3.

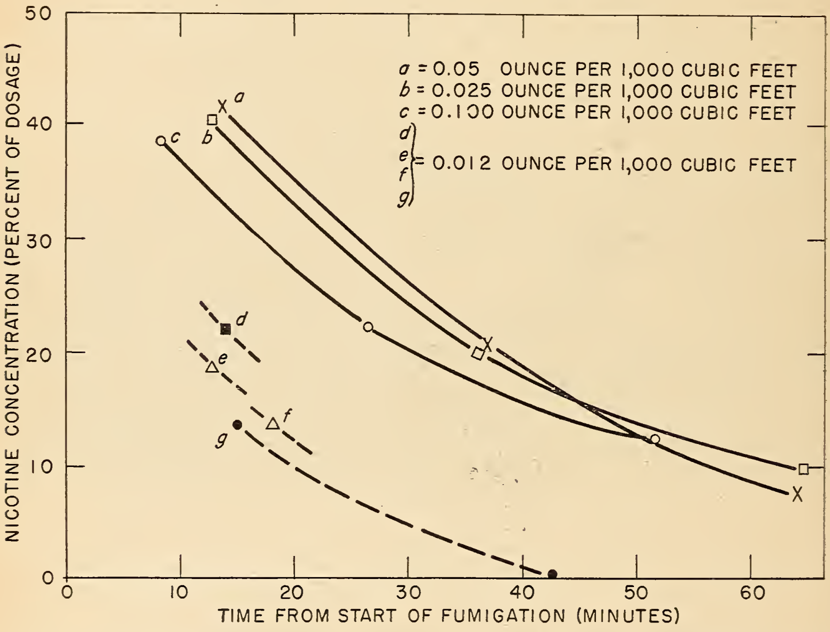

FIGURE 3.—Nicotine concentrations obtained in greenhouse by atomizer method at various dosages: *a*, 0.05 ounce per 1,000 cubic feet; *b*, 0.025 ounce per 1,000 cubic feet; *c*, 0.100 ounce per 1,000 cubic feet; *d*, *e*, *f*, *g*, 0.012 ounce per 1,000 cubic feet. Dry conditions in all cases except with one of the 0.012-ounce dosages. Each point is the average of two or three analyses at different locations.

Nicotine concentrations were near 40 percent of the dosage soon after the start but fell off rapidly so that little remained after 1 hour. As can be seen, the amounts of nicotine in the air are quite similar on a percentage basis for dosages of 0.1[4] down to 0.05 and 0.025 ounce but are much lower at the 0.012-ounce dosage. Possibly sorp-

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[3] All dosages of nicotine are hereafter given in this unit. That is, a 0.15-ounce dosage equals 0.15 ounce per 1,000 cubic feet.

[4] This equals the commonly recommended dosage of ¼ ounce of 40-percent nicotine per 1,000 cubic feet, or approximately 0.1 mg. per liter.

tion and other factors had a more pronounced effect here, but these last concentrations were down near the lowest limit for accurate analyses. The insecticidal results are shown in table 1.

TABLE 1.—*Efficiency of nicotine fumigation with the atomizer apparatus at various dosages and moisture conditions. Overnight exposures except as noted. Fumigations made in No. 2 greenhouse except tests 8, 9, and 11, which were made in No. 1 greenhouse, and test 1, made in No. 4 greenhouse. Temperature varied from 62° to 72° F. over the first hour in all tests except test 16, where it was 56° to 58°*

Test No.	Dosage of nicotine per 1,000 cubic feet	Relative humidity over first hour	Condition of soil and plants	Location of insects[1]	Mortality of insects: *Myzus persicae*	Mortality of insects: *Macrosiphum solanifolii*	Mortality of insects: *Myzus porosus*
	Ounce	*Percent*			*Percent*	*Percent*	*Percent*
11	0.16	45–80	Damp	N	99.4		
9	.13	60–61	do	N, C	94.7		
1	.10	65–67	do	S			100.0
1a	.10	15–54	Dry	N		100.0	
				C		99.7	100.0
				S		99.3	
				C[2]		91.8	
8	.10	66–66	Damp	N		100.0	
				C, S	95.0		
2	.05	30–52	Dry	N		95.3	100.0
				C		99.5	100.0
				S		95.3	96.8
5	.05	60–52	Damp	N		99.5	
				C	96.5	98.2	
				S		98.8	
				N, C, S[2]		79.4	
3	.025	18–36	Dry	N		93.5	100.0
				C		99.8	100.0
				S		99.0	100.0
6	.012	48–48	do	N		96.4	
				C		97.2	
				S		95.3	
				C[2]	70.5		97.5
7	.012	92–75	Wet	N	[3] 54.1	89.8	
				C	[3] 77.4	97.6	62.7
				S	[3] 42.7	65.8	
				N, C	20.9		
13	[4] .012	18–42	Dry	N	25.1	66.8	8.8
				C	59.8	86.0	0
				S	11.3	51.9	0
15	[4] .012	8–20	do	N	67.6	71.9	38.8
				C	48.2	78.9	46.3
				S	36.0	72.3	11.4
16	.012	76–70	Damp	N	51.5	90.0	
				C	40.0	91.3	
				S	50.3	76.7	
21	.012	36–40	Dry	N	56.8	68.6	35.9
				C	71.4	73.9	36.0
				S	18.9	40.8	16.3

[1] N=North; C=center; S=south.
[2] Placed in fumigation 1 hour after the start.
[3] *Myzus persicae* on radish.
[4] Water solution used in place of acetone solution of nicotine.

A high kill of the various aphids was obtained with dosages down to 0.025 ounce, but efficiency was generally lower and erratic at the 0.012-ounce dosage.

Good distribution was given by the atomizer method as indicated by the chemical analyses. For example, in fumigation test 1a there were 0.043 and 0.038 mg. of nicotine per liter at the north and south ends, respectively, 8 minutes after the start. After 26 minutes the concentrations were 0.021, 0.021, and 0.027 mg. at the north, center, and south positions, respectively. The respective figures after 51 minutes were 0.014, 0.011, and 0.013 mg. Analyses of the other fumi-

gations corroborated these results. Later tests indicated that a 5-minute diffusion period gave as good distribution as a 15-minute period at a 0.05-ounce dosage. The insecticidal results (table 1), also indicate good distribution of nicotine except at the lowest dosage (0.012-ounce). Here the mortality varied, being generally higher at the center and north end and lowest at the end of the greenhouse adjacent to the apparatus. This coincides with the probable flow of air, indicating that much of the nicotine at this low dosage had been taken up by the time it circulated back to the machine.

The atomization of water solutions (*17*) instead of acetone solutions of nicotine seemed to give somewhat lower efficiency (tests 13 and 15, compared with test 6, table 1, all under dry conditions). There were little differences, however, in nicotine analyses at these very low dosages. Further tests indicated that no increase in efficiency would be obtained by using 90-percent instead of approximately 60-percent acetone solutions (by volume), or by atomizing the nicotine at a 30° angle rather than level with the ground.

The pressure can, tobacco smudge, and nicotine papers were tested at the dosage recommended by the manufacturers. The analytical results are shown in figure 4. As can be seen the pressure-can and

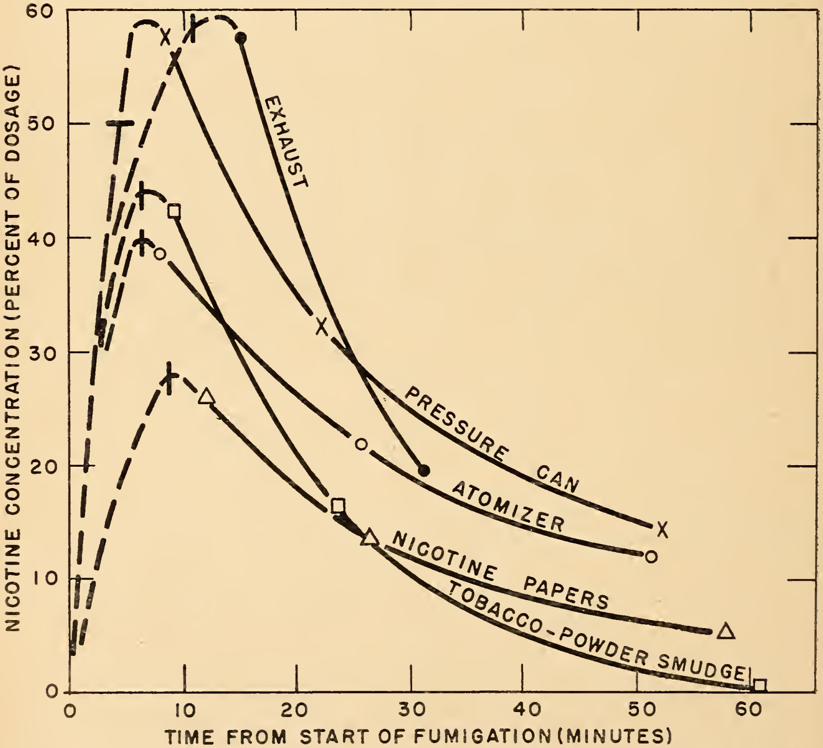

FIGURE 4.—Nicotine concentrations obtained in the greenhouse by different methods of vaporization. The dosages are given in table 2, the one for the pressure can being 0.09 ounce of nicotine per 1,000 cubic feet. Points on lines are averages of 2 or 3 analyses made in different locations. Short cross lines near the start show the time of completion of the application of the dosage for each method.

exhaust methods gave near 60 percent of the dosage, the tobacco smudge and atomizer near 40 percent, and nicotine papers near 30 percent at 10 to 15 minutes from the start. Approximately 11 minutes were required for vaporization of the dosage by the exhaust method, so the first analyses were made later than those for the other methods. Damp conditions were present in the tests with the exhaust and smudge methods and were responsible apparently for the rapid fall in concentration (see later discussion).

Insecticidal results are shown in table 2.

TABLE 2.—*Efficiency of nicotine fumigation with various methods of vaporization. Overnight exposures except as noted. All fumigations made in No. 2 greenhouse. Temperature during first hour varied from 65° to 72° F. except for the 0.012 dosage of the pressure can under damp conditions, where it was 60°*

Method of vaporization	Dosage of nicotine per 1,000 cubic feet	Relative humidity over first hour	Condition of soil and plants	Location of insects [1]	Mortality of insects: *Myzus persicae*	Mortality of insects: *Macrosiphum solanifolii*	Mortality of insects: *Myzus porosus*
	Ounce	*Percent*			*Percent*	*Percent*	*Percent*
Pressure can	0.09	12–40	Dry	N	90.0	100.0	—
				C	92.6	100.0	—
				S	96.3	99.8	—
				N [2]	—	93.3	—
	.09	84–80	Damp	N	95.8	—	—
	.012	12–40	Dry	N	44.1	83.3	—
				C	67.0	84.7	—
				S	30.9	20.7	—
				C [3]	—	54.4	—
	.012	88–91	Damp	N	—	47.0	—
				C	—	58.1	—
				S	—	52.3	—
				C [3]	—	33.3	—
Nicotine papers	.04	25–30	Dry	N	90.6	100.0	88.1
				C	91.4	100.0	99.1
				S	95.2	100.0	97.6
Tobacco smudge	.06	56–60	Damp	N	66.8	89.1	—
				C	74.4	93.0	—
				S	79.5	87.3	—
Exhaust	.05	64–71	do	N	58.7	84.4	96.8
				C	97.3	99.5	99.8
				S	73.9	93.3	84.0

[1] N=north; C=center; S=south.
[2] Insects exposed after first hour.
[3] Insects exposed for first half hour only.

Because of the different dosages no close comparisons of efficiency can be made. The pressure can at a 0.09-ounce dosage (dry and damp conditions) appeared just as effective against the aphids as the atomizer at the 0.1-ounce dosages under similar conditions (table 1, tests 1, 1a, and 8). Two small home-made cans were charged with a 0.012-ounce dosage but, when tested, the efficiency seemed somewhat lower than that given by the atomizer (compare with dry and damp fumigations tests 6 and 7, table 1). These small cans may not have been exactly like the commercial product, however. At the recommended dosage, both the insecticidal and chemical results indicate that the pressure can gave good distribution. The exhaust method did not appear to differ greatly from the atomizer method in efficiency (table 1, test 5), but the mortality distribution was uneven. The provision of a blower would probably rectify this. Tobacco-powder smudge seemed less effective than the atomizer mist. Nicotine papers gave good distribution and appeared fully as effective as the atomizer (table 1, test 2), in contrast to the analytical results shown in figure 4.

According to present-day retail prices the atomizer and exhaust methods cost approximately 0.69 cent per gram of nicotine used, the pressure can 0.92 cent, tobacco smudge 1.1 cents, and nicotine papers 1.6 cents (quantities of $8–$10 worth). This is the full cost for the last three but for the first two there is the additional cost for the apparatus, gasoline, oil, and depreciation. The pressure-can method appears to be about as low in cost as any of the methods, and chemical and insecticidal results indicate relatively high efficiency. It is also a very convenient and safe method of fumigation.

EFFECT OF DRY AND MOIST CONDITIONS ON FUMIGATION

Anderson and Roth (*2*) and McDaniel (*8*) recommend a moist atmosphere for nicotine fumigation. Manufacturers have also recommended moist conditions. On the other hand Herrick and Griswold (*5*) and C. H. Richardson and Haas (*9*) found relative humidity of little importance. H. H. Richardson and Busbey (*11*), working with very low gas concentrations, obtained higher aphid mortality at low relative humidity but after passing the nicotine-air mixture

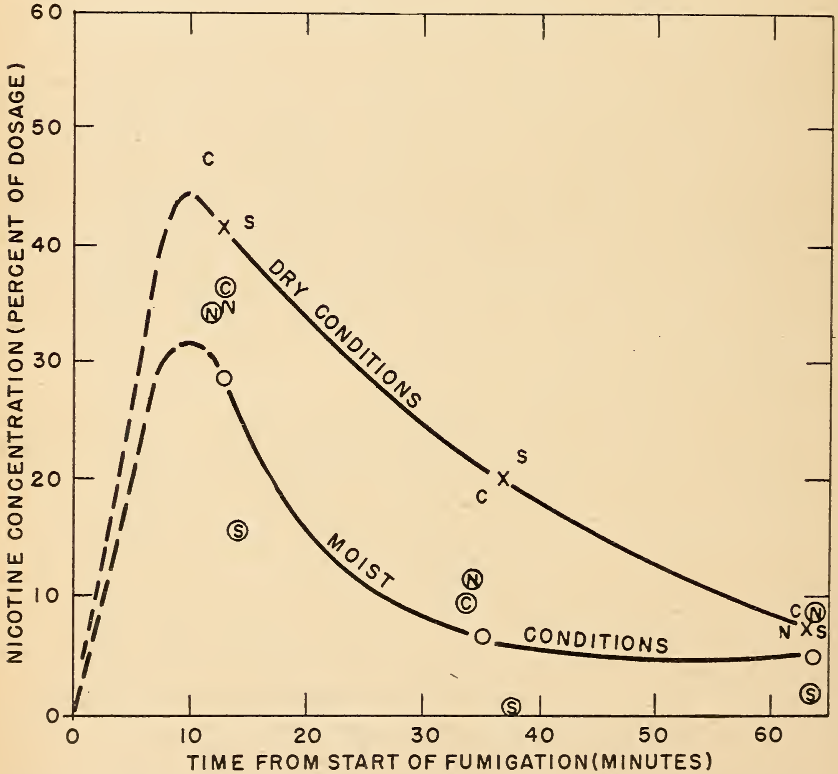

FIGURE 5.—Nicotine concentrations obtained in a greenhouse under dry and moist conditions of fumigation (tests 2 and 5, respectively, table 1) with atomizer apparatus.

through the fumigation chamber for 2 to 3 hours there was little difference at either high or low humidity. In the present work three series of comparisons of dry and moist conditions were made using the atomizer method. At the 0.012-ounce dosage aphid mortality was uneven and averaged lower under wet conditions than under dry conditions (table 1, tests 6 and 7). Under damp conditions (test 16) the results were intermediate. Nicotine concentrations were all near the lowest limit for accurate analysis.

At the 0.05-ounce dosage there was high kill of aphids under both dry and damp conditions (table 1, tests 2 and 5), but the nicotine concentrations were much lower under moist conditions (fig. 5).

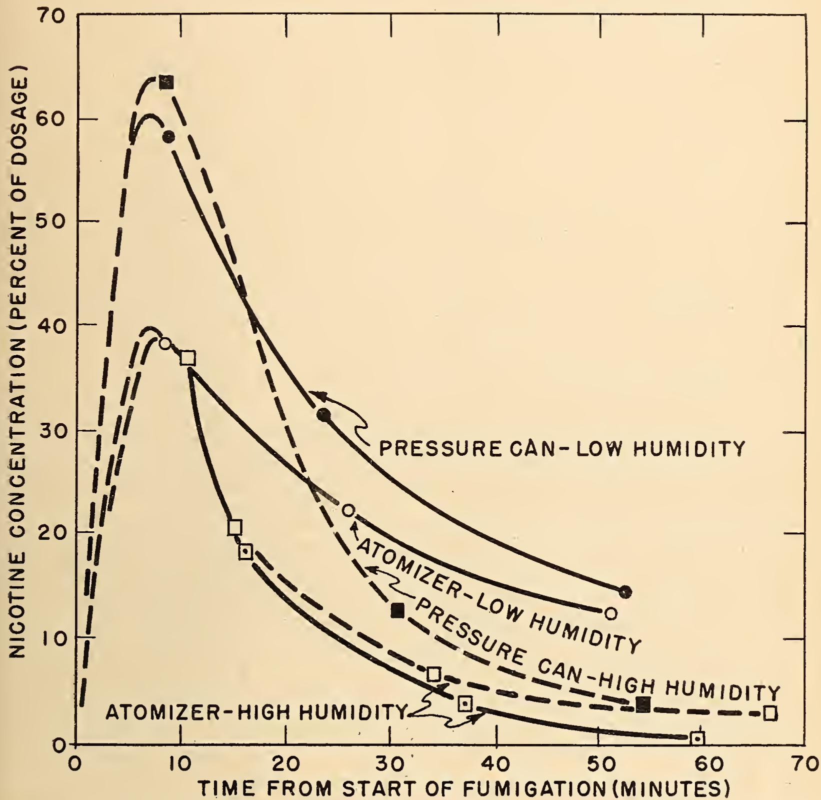

FIGURE 6.—Nicotine concentrations obtained in the greenhouse under dry (low humidity), and damp (high humidity), conditions. The two pressure-can tests were at 0.09-ounce of nicotine per 1,000 cubic feet. The three atomizer tests were at 0.1 ounce (tests 1, 1a, and 8, table 1). Points on lines are averages of 2 or 3 analyses at different locations.

At the 0.1-ounce dosage there was a high kill of aphids in all cases (table 1, tests 1, 1a, and 8). Under dry conditions (1a) there was also 98.5 percent kill of the greenhouse white fly (*Trialeurodes vaporariorum* (Westw.)), compared with 57.4 percent kill under damp conditions (test 8). Nicotine concentrations fell away much faster in all the fumigations at high humidity (fig. 6).

Two series of comparisons were made with the pressure can (table 2). Killing efficiency was generally greater under dry conditions at the 0.012-ounce dosage (the uneven kill in the dry fumigation was apparently due to an uneven placement of the cans). Nicotine concentrations were definitely higher under the dry conditions (39 versus 25 percent of the dosage at 16 minutes from the start).

At the 0.09-ounce dosage (table 2), there was high mortality of aphids exposed overnight in both cases. Efficiency appeared higher under dry conditions in certain other tests with *Myzus persicae* not here reported. Nicotine concentration with the 0.09-ounce dosage fell away much faster in the damp fumigation (fig. 6). This rapid fall in nicotine concentration under damp conditions was also noted with the exhaust and smudge methods (fig. 4; conditions shown in table 2).

In general, lower insecticidal efficiency was obtained under damp or wet conditions at the lower nicotine dosages,[5] but at higher dosages the differences were small or inconsistent. Nicotine concentrations were lower or fell away faster under damp or wet conditions.

In most of the above fumigations the foliage of the test plants was kept free of moisture even under otherwise damp or wet conditions. It is probable that if moisture was present on or near the insects on the infested plant foliage, fumigation efficiency would be much lower.

EFFICIENCY OF VARIOUS LENGTHS OF FUMIGATION PERIOD

An overnight fumigation is generally used with nicotine (*8*), but the manufacturers of the pressure can state that where time is limited a 1-hour fumigation will give effective insect control. Alsterlund and Compton (*1*), however, obtained very erratic kill of the susceptible (*12*) *Macrosiphoniella sanborni* (Gill.) in 1-hour exposures with the can placed at the center of the greenhouse.

The chemical results already given (figs. 3–6), indicate very definitely that the nicotine concentration in the greenhouse falls rapidly soon after the start with the result that little nicotine remains after 1 hour with the various methods of vaporization tested. Analysis after 2 hours showed only 2.9 percent of a 0.1-ounce dosage in an atomizer fumigation.

The results of tests in which aphids were exposed to only the first 30 and 60 minutes of fumigation, as compared with an entire overnight exposure, are shown in table 3.

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[5] Unpublished data by the senior author have confirmed this in laboratory tests with an airflow apparatus (*11*). The adverse effect of high relative humidity was noted at concentrations of near 0.005 mg. nicotine per liter or below. But at 0.008 mg. or higher concentrations, there was little difference in results with either high or low relative humidity.

TABLE 3.—*Efficiency of first 30 and 60 minutes of nicotine fumigation as compared with 16- to 17-hour overnight exposures by various methods and dosages. Temperature during first hour ranged from 62° to 72° F. except in the fourth atomizer fumigation, where it was 56° to 58°. Damp conditions except where noted*

Method of vaporization	Dosage of nicotine per 1,000 cubic feet	Mortality of *Macrosiphum solanifolii* exposed to fumigation—		Mortality of *Myzus persicae* exposed to fumigation—	
		First 30 minutes	16 to 17 hours (overnight)	First 30 minutes	16 to 17 hours (overnight)
	Ounce	*Percent*	*Percent*	*Percent*	*Percent*
Atomizer	[1] 0.012	46.1	60.0	39.6	42.5
	[1] .012	47.8	68.7	28.4	32.8
	[1] .012	72.0	75.0		
	.012	72.9	87.6	29.5	44.2
Average		59.7	72.8	32.5	39.8
Pressure can	[1] .012	54.4	71.8	25.9	44.7
	.012	33.3	53.3		
	.09			70.4	95.8
Average		43.8	62.5		
Smudge	.06	76.3	98.9	62.5	75.5
Exhaust	.05	87.9	92.3	62.6	77.3
		First 60 minutes		First 60 minutes	
Atomizer	.16			98.4	99.4
Pressure can	.09	100	100	89.4	92.9
Nicotine paper	.04	100	100	83.3	92.3

[1] Dry conditions.

As can be seen, a considerable kill took place in the first 30 minutes. For the atomizer method, this amounted to 82.0 and 81.7 percent of the average kill occurring in an entire overnight exposure. The figures for the other methods ranged from 58.5 to 95.2 percent. In general, it appears that near 80 percent of the killing action takes place in the first 30 minutes. The mortality occurring in the first 60 minutes ranged from 90 to 100 percent of that produced by the overnight exposure with the methods tested. Apparently a 60-minute exposure will give nearly the same efficiency as an entire overnight fumigation under the conditions tested. This seems to agree well with the chemical results.

Although the tests just discussed indicate that most of the insecticidal action occurred in the first hour, it was important to note whether exposure after the first hour to the remainder of the overnight fumigation would have much effect. In three fumigations with *Myzus persicae* at 0.04- to 0.16-ounce dosages, the mortalities for those missing the first hour and those exposed to the entire fumigation were as follows: 38 vs. 92 percent, 81 vs. 93 percent, and 62 vs. 99 percent. Similar results were obtained in five fumigations with *Macrosiphum solanifolii* with dosages as low as 0.025 ounce. The insecticidal action taking place after 1 hour apparently depends on the nicotine concentration present then, which in turn depends on the original dosage and conditions. For example, in the tests with *Myzus persicae* the nicotine concentrations were 0.002, 0.005, and 0.013 mg. per liter

and mortalities were 38, 62, and 81 percent, respectively. Similar correlations were noted for tests with *Macrosiphum solanifolii*. The concentrations with the 0.012-ounce dosages were very small after 1 hour and had little effect.

Although no chemical tests were made after the first 2 hours of fumigation, it appears that very low concentrations of nicotine remain in the atmosphere for some time after the first hour with the usual dosages, but that these have a considerable effect against previously unexposed insects. This is in contrast to the effects of methyl bromide, where little insecticidal action occurred after gas concentration had become low (*13*).

RESISTANCE OF VARIOUS INSECTS

In a series of nine comparisons, *Myzus persicae* on turnip and *M. porosus* on rose appeared to be the most resistant aphids (averaging 54.6 and 58.0 percent mortality, respectively), while *Macrosiphum solanifolii* on lettuce was much less resistant (79.1 percent mortality). Individuals of *Myzus persicae* grown on radish were found much less resistant than those on turnip (average of 57.6 versus 20.9 percent kill), which is similar to previous findings with this insect (*12*). *Aphis gossypii* on cucumber appeared even less resistant than *Macrosiphum solanifolii* (89.1 versus 79.7 percent average kill in six paired tests). *Aphis rumicis* on nasturtium also appeared less resistant than *Macrosiphum solanifolii* in a few preliminary tests.

Four fumigations indicated *Thrips tabaci* Lind, on onion was somewhat more resistant than *Myzus persicae* on turnip (averaging 78 versus 94 percent kill, respectively). In five fumigations, adults of *Trialeurodes vaporariorum* on tomato appeared to be slightly more resistant than the adult *Thrips tabaci* (averaging 70 versus 76 percent, respectively). At dosages of 0.1 ounce or more the majority of white flies appear paralyzed soon after the start, but many appear to recover and start to fly about after 30 to 40 minutes while still in the fumigation.

Phenacoccus gossypii T. and C. on chrysanthemum and *Tetranychus bimaculatus* Harvey on rose were the most resistant species tested. Very little mortality was obtained with the ordinary dosages of nicotine, confirming previous work with the former insect (*10*).

From a practical standpoint the results indicate that the different aphids can be controlled by a 0.05- to 0.1-ounce dosage of nicotine per 1,000 cubic feet of space. With a susceptible aphid such as *Macrosiphum solanifolii* this dosage can probably be reduced. The 0.1-ounce dosage will kill considerable numbers of white flies and thrips, but a series of repeated fumigations would probably be needed for control.

TOLERANCE OF VARIOUS PLANTS

Lettuce (*Lactuca sativa* L.) was given the most extensive tests on plant tolerance. One crop, filling No. 2 greenhouse, was given 4 fumigations at approximately weekly intervals with 0.1- to 0.025-ounce dosages. A second crop of lettuce received a total of 12 fumigations with 0.1- to 0.012-ounce dosages beginning with one shortly after the plants had been transplanted into the greenhouse and continuing for

approximately 2 months until the plants were fully mature. In several of these fumigations the crop was exposed to sunshine during the first hour or more. Both crops appeared to be in excellent condition when harvested.[6]

A crop of tomatoes (*Lycopersicon esculentum* L.) in No. 1 greenhouse received a total of four fumigations at 0.1- to 0.16-ounce dosages over a period of 12 days. In three of these sunlight was present for approximately the first hour. No indication of injury could be seen on the tomatoes, which were growing rapidly at the time of the fumigations.

The following plants were fumigated with 0.1- to 0.16-ounce dosages without injury:

Allium sp.	*Hedera helix* L.
Amaryllis sp.	*Iris* sp.
Antirrhinum majus L.	*Lantana camara* L.
Begonia semperflorens Link and Otto	*Lilium* sp.
Beta vulgaris var. *circla* Moq.	*Lycopersicon esculentum* L.
Brassica rapa L.	*Nephrolepis exaltata* Schott
Coleus blumei Benth	*Pelargonium hortorum* Bailey
Cucumis sativus L.	*Poinsettia* sp.
Cuphea ignea D. C.	*Rhododendron* sp.
Delphinium sp.	*Rosa dilecta* Rehd.
Gerbera sp.	*Saintpaulia* sp.
Gladiolus sp.	*Vinca* sp.

In addition to the above the following were fumigated without injury in No. 4 greenhouse using 0.1- to 0.16-ounce dosages:

Acalypha wilkesiana Muell. Arg.	*Codiaeum* sp.
Chrysanthemum hortorum Hort.	*Tropaeolum majus* L.

SUMMARY

Chemical and insecticidal tests were made with five methods of vaporizing nicotine as a fumigant and on other factors affecting its efficiency.

Nicotine concentrations were highest soon after the start of fumigation but fell off rapidly with all the methods with the result that little nicotine remained after the first hour. The atomizer method gave a concentration near 40 percent of the dosages of 0.025 to 0.1 ounce per 1,000 cubic feet 8 to 10 minutes after starting, but at a 0.012-ounce dosage the gas concentrations were disproportionately lower and distribution varied. Insecticidal action against various aphids was good at the higher dosages but was generally lower and distribution varied at the lowest dosage. The atomization of water solutions instead of acetone solutions of nicotine appeared less effective. Concentrations near 60 percent of the dosage were given by the pressure-can and exhaust methods, near 40 percent by the smudge method, and near 30 percent by nicotine papers (10 to 15 minutes after the start). The pressure can appeared very effective and gave good distribution in insecticidal tests. The exhaust method was effective, but distribution was uneven with this apparatus. The use of a blower would probably rectify this. The smudge method gave good distribution, but its effi-

[6] Apparently lettuce takes up some nicotine in the fumigation. A content of 28 parts per million was found 1 day after the last of a series of four fumigations at a 0.025-ounce dosage made at 1-day intervals. Whether this is important from the residue standpoint has not been determined.

ciency seemed less than that obtained with the atomizer. Nicotine papers gave good distribution and appeared more effective than would be indicated by chemical tests. The pressure-can method was one of the cheapest, most effective, and convenient methods of those tested.

Damp or wet soil and high relative humidity appeared to lower efficiency at the lower dosages but had little effect at the higher dosages. Nicotine concentrations were generally lower or fell away faster under damp or wet conditions than when the plants and soil were dry. Wetting the infested foliage will probably lower the efficiency.

There was no indication of a carry-over of nicotine in a greenhouse given repeated fumigations at dosages of 0.05 to 0.1 ounce per 1,000 cubic feet.

Approximately 80 and 95 percent of the insecticidal action in fumigation by the various methods took place in the first 30 and 60 minutes, respectively. Chemical analyses corroborate this. The very low nicotine concentrations present at the end of the first hour of fumigation with dosages of 0.025 ounce or more per 1,000 cubic feet had considerable toxic effect against aphids exposed from then on to the remainder of the 16- to 17-hour, overnight exposure.

The resistance of the various insects tested to nicotine fumigation seemed to be in the following increasing order:

(1) *Aphis rumicis* on nasturtium and *Aphis gossypii* on cucumber (least resistant),
(2) *Macrosiphum solanifolii* on lettuce,
(3) *Myzus persicae* on radish,
(4) *Myzus porosus* on rose and *M. persicae* on turnip,
(5) *Thrips tabaci* on onion,
(6) *Trialeurodes vaporariorum* on tomato. *Phenacoccus gossypii* on chrysanthemum, and *Tetranychus bimaculatus* on rose were the most resistant.

Repeated fumigations with nicotine produced no apparent injury to crops of lettuce and tomato and various other plants.

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